Sample of Cataclysmic Variables from 400d X-ray Survey

R. Burenin[1], M. Revnivtsev[1], A. Tkachenko[1], V. Vorobyev[1], A. Semena[1], A. Meshcheryakov[1], S. Dodonov[2], M. Eselevich[3], and M. Pavlinsky[1]

[1]*Space Research Institute, Moscow, 117997 Russia;*

[2]*Special Astrophysical Observatory, Nizhnii Arkhyz, 369167 Russia;*

[3]*Institute of Solar-Terrestrial Physics, Irkutsk, 664033 Russia;*

Abstract.

We present a sample of eight cataclysmic variables (CVs) identified among the X-ray sources of the 400 square degree (*400d*) X-ray ROSAT/PSPC survey. Based on this sample, we have obtained preliminary constraints on the X-ray luminosity function of CVs in the solar neighbourhood in the range of low luminosities, $L_X \sim 10^{29}$–10^{30} erg s^{-1} (0.5–2 keV). We show that the logarithmic slope of the CV luminosity function in this luminosity range is less steep than that at $L_X > 10^{31}$ erg s^{-1}. Our results show that of order of thousand CVs will be detected in the SRG/eROSITA all-sky survey at high Galactic latitudes, which will allow to obtain much more accurate measurements of their X-ray luminosity function.

1. Introduction

One of the most natural way to select statistically complete samples of cataclysmic variables (CV) is to detect them as X-ray sources in large area surveys. Almost all of the objects detected in various X-ray sky surveys to date (see, e.g., Sazonov et al. 2006; Pretorius et al. 2007b; Revnivtsev et al. 2008) had an X-ray luminosity $L_X > 10^{30}$ erg s^{-1} in the 0.5–2 keV energy band. Measurements of the CV number density at luminosities $L_X < 10^{30}$ erg s^{-1} will provide new valuable information for CV population studies.

To study the X-ray luminosity function of CVs at lower X-ray luminosities we used the 400 square degree (400d) survey based on ROSAT/PSPC pointings (Burenin et al. 2007). The preliminary results of the search for CVs among the X-ray sources of this survey were presented by Tkachenko et al. (2015). In this contribution we discuss the results of CV X-ray luminosity function measurements based on X-ray CV sample obtained to date, further details can be found in Burenin et al. (2016a).

2. CV Selection

To search for point sources we used the central part of the ROSAT field of view with diameter $< 37'$ in which the angular resolution is $\leq 70''$ (FWHM). The average positional accuracy for an X-ray source is at least $10''$ (at 95% confidence). We used 1605 ROSAT pointings in the 0.5–2 keV band at high Galactic latitudes $|b| > 25°$.

Table 1. Cataclysmic variables detected in the 400d survey

Name	$m_{g'}$	f_X erg s^{-1}cm^{-2}	L_X erg s^{-1}	Alternative name
400d j001912.9+220736	19.61	4.84×10^{-14}	$^{*}6.4 \times 10^{29}$	SDSS J001912.58+220733.0
400d j050146.2−035914	18.41	1.78×10^{-13}	5.8×10^{30}	HY Eri
400d j124325.7+025541	17.72	5.51×10^{-13}	$^{*}1.3 \times 10^{30}$	1E 1240.8+0312
400d j152212.8+080338	18.99	1.58×10^{-13}	$^{*}1.2 \times 10^{30}$	SDSS J152212.20+080340.9
400d j154730.1+071151	16.34	1.16×10^{-13}	2.0×10^{29}	
400d j160002.4+331120	19.89	8.87×10^{-14}	$^{*}1.5 \times 10^{30}$	VW CrB
400d j160547.5+240524	19.78	5.47×10^{-14}	$^{*}8.5 \times 10^{29}$	
400d j204720.3+000008	19.36	4.19×10^{-14}	$^{*}4.4 \times 10^{29}$	SDSS J204720.76+000007.7

* The rough estimate of the X-ray luminosity L_X (for more details, see the text).

The geometric area of the 400d survey for point sources is 436.7 sq. deg. The geometric area of the 400d survey overlapping with SDSS photometric fields is 262.3 sq. deg. At X-ray flux $\approx 2.5 \times 10^{-14}$ erg s^{-1}cm^{-2} (0.5–2 kwV) the survey area is equal to half of the geometric area. In this survey more than 37 000 X-ray sources with fluxes above 10^{-14} erg s^{-1}cm^{-2} were detected. About 22 000 of these sources were detected in the fields where there is an overlap with SDSS fields.

For the identification of X-ray sources from the 400d survey we used data from the 12th release of the SDSS (Alam et al. 2015) and the WISE infrared all-sky survey (Wright et al. 2010). The CV optical spectrum should be dominated in its the blue part by the emission from the WD and the accretion disk. Therefore, for the selection of CV candidates, we used the criterion $u' - g' < 0.7$. To eliminate a large number of quasars, which strongly contaminate the CV sample, we additionally eliminated the objects with colors $w_1 - w_2 > 0.6$, where w_1 and w_2 are the photometric bands of the WISE infrared all-sky survey (Wright et al. 2010). This spectral range corresponds to the Rayleigh-Jeans part of the spectrum for the majority of stars, therefore the CV color shgould be $w_1 - w_2 \approx 0$.

We selected CV candidates with g' magnitudes < 20.0. Even when the contribution of the accretion disk is small and the WD contribution dominates in the spectra of CVs, their absolute magnitudes are $M_{g'} \approx 12$ (Gänsicke et al. 2009; Revnivtsev et al. 2014). Therefore, the limit $g' < 20.0$ for such systems corresponds to a distance of about 400 pc, which is approximately equal to the thickness of the Galactic disk.

There are 53 objects satisfying the criteria listed above in the 400d survey. Some of them(four objects) turned out to be previously known CVs. To identify the nature of the remaining objects, we carried out additional optical observations.

3. Optical Observations of CV Candidates

The additional optical observations were carried out with the Russian-Turkish 1.5-m telescope (RTT150) using TFOSC instrument[1], the 6-m (BTA) telescope at the Special Astrophysical Observatory of the Russian Academy of Sciences using SCORPIO spectrograph (Afanasyev, Moiseev 2005), and with the 1.6-m AZT-33IK telescope at the

[1]http://hea.iki.rssi.ru/rtt150/en/index.php?page=tfosc

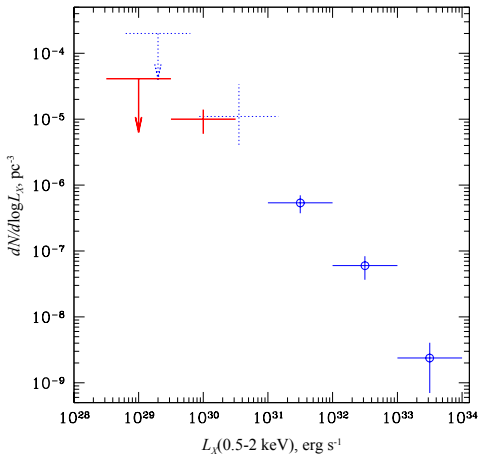

Figure 1. Constraints on the CV luminosity function. The blue circles indicate the measurements of the X-ray luminosity function based on RXTE data (Sazonov et al. 2006) recalculated to the 0.5–2 keV energy band under the assumption of a power-lawspectrum $dN/dE \propto E^{-1.6}$. The dotted blue crosses indicate the constraints on the luminosity function from the the ROSAT North Ecliptic Pole survey (Pretorius et al. 2007b).

Sayan Observatory, Russia, using newly installed ADAM spectrograph (Afanasyev et al. 2016; Burenin et al. 2016b). We observed 34 objects, four of which turned out to be new, previously unknown CVs. The spectra for two of them were later also obtained in the SDSS. The remaining objects turned out to be quasars at various redshifts, typically at z = 1–2. Basic information about the CVs in our sample is presented in the table. To date we have failed to measure the spectra for 15 objects with magnitudes $19.5 < g' < 20$, this work will be continued in future.

4. Constraints on the CV Luminosity Function in the Solar Neighbourhood

We detected eight CVs, with more or less reliable distance estimates being available only for two of them. To make rough, preliminary estimates of the luminosity function, we assume that the remaining systems have low X-ray luminosity. In this case, their absolute magnitude should be near a minimum CV absolute value of $M_{g'} \approx 12$, which is observed due to the presence of a WD in the system (Revnivtsev et al. 2014). The X-ray luminosities that are derived for systems with unknown distances under the assumption of $M_{g'} \approx 12$ are given in the table and marked by an asterisk. The distance estimates for these systems turn out to be within the range 200–300 pc. Some of the systems (for example, 400d j124325.7+025541, 400d j152212.8+080338 and 400d j204720.3+000008) can actually have a higher luminosity. However, the luminosity of all these systems, on average, cannot be much higher, because, in this case, the objects should be located at larger distances, but at high Galactic latitudes the space density of sources drops rapidly at distances greater than the thickness of the Galactic disk.

Based on these data, we can obtain a preliminary constraint on the X-ray luminosity function of CVs. The dependence of the density of sources in the Galactic disk on

the perpendicular distance from the Galactic plane, $\rho(z) = \rho_0 e^{-|z|/h}$, can be taken into account by calculating a generalized volume Pretorius et al. (2007b). We assume that the exponential scale height of the Galactic disk for our CVs is 260 pc, which corresponds to the disk scale height for old, short-period systems (Pretorius et al. 2007a). The sample incompleteness can be taken into account statistically by appropriately increasing the measurement errors.

The X-ray luminosities of the six systems from our sample are 3×10^{29}–3×10^{30} erg s^{-1}. Taking into account all of the aforesaid, we obtain the following constraint on the CV space density based on this sample: $\rho_0 = 1.0 \pm 0.4 \times 10^{-5}$ pc^{-3}. Only one system, 400d j154730.1+071151, with a luminosity close to the upper boundary of the luminosity range 3×10^{28}–3×10^{29} erg s^{-1} falls within this range. In this case, the upper limit on the CV space density for this range is $\rho_0 < 4.1 \times 10^{-5}$ pc^{-3} (at 95% confidence). This system may be classified as a pre-cataclysmic variable. If such systems are not considered as CVs, then the limit on the CV space density is $\rho_0 < 2.7 \times 10^{-5}$ pc^{-3}.

Our constraints on the X-ray luminosity function of CVs are shown by the solid red crosses in Fig. 1. The constraints from previuos studies are also shown in this Figure. Our constraint on the CV space density near $L_X \approx 10^{30}$ erg s^{-1} agrees well with that from Pretorius et al. (2007b). We obtained a stronger upper limit on the CV space density near an X-ray luminosity $L_X \approx 10^{29}$ erg s^{-1}. The comparison of our constraints with the luminosity function at $L_X > 10^{31}$ erg s^{-1} derived previously (Sazonov et al. 2006) shows that its slope becomes less steep at low luminosities (see Fig. 1).

The area of 400d X-ray survey is approximately 1% of all-sky, and its depth is approximately equal to the depth of future SRG/eROSITA survey. Therefore, our results show that in SRG/eROSITA all-sky survey of order of thousand CVs will be detected at high Galactic latitudes, which will allow to obtain much more accurate measurements of their X-ray luminosity function.

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